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ANNEXES

526 Rec'd PCT/PTO 20 NOV 2000

Amendments

However, while the selection ratio of the SiO_2 film layer relative to the SiN_x film layer is improved due to the presence of the carbon film formed at the inner wall surface of the contact holes by forming the contact holes using a mixed gas containing C_4F_8 and CO as described above, carbon becomes accumulated also at the bottoms of the contact holes. This results in the carbon accumulated at the bottoms of the contact holes preventing the fluorine radicals from reaching the bottoms with ease. Consequently, it becomes difficult to mill contact holes having a depth larger than a specific measurement, to lead to a reduction in the penetration and an etching stop.

In addition, while it has become one of the technological requirements in recent years to form contact holes achieving a high aspect ratio in extremely small spaces between gates, the structure of such deep contact holes makes it difficult for fluorine radicals to reach the bottoms of the contact holes. As a result, if the contact holes are formed by using the mixed gas containing C_4F_8 and CO as described above, the accumulation of carbon at the bottoms of the contact holes and the reduction in the quantity of fluorine radicals entering the contact holes further reduce the penetration and increases the occurrence of etching stop.

Furthermore, if contact holes are formed through a process in which carbon is accumulated readily at the bottoms of the contact holes as in the etching method in the prior art described above, it is necessary to perform over-etching on the semiconductor substrate in consideration of carbon which accumulates at the bottoms of the contact holes. However, if such an over-etching process is performed on the semiconductor substrate, the insulating film layer and the SiN_x film layer, which are respectively provided to cover and protect the

gates are also etched, to result in the insulating film layer and the gates themselves becoming exposed inside the contact holes.

Consequently, problems such as defective insulation and shorting of the gates, other wiring or electrodes may occur to lower the yield. In particular, the shoulder (corners) of the SiN_x film layer, which often distend into the contact holes, tend to become etched very readily, and thus, if over-etching process is performed on the semiconductor substrate as described above, the worst damage is likely to occur at the corners. For this reason, the etching process can only be performed to an extent to which the shoulder of the SiN_x film layer do not become damaged in the etching method in the prior art, which makes it extremely difficult to form contact holes achieving a high aspect ratio.

A first object of the present invention, which has been completed by addressing the problems of the prior art discussed above, is to provide a new and improved etching method which achieves an improvement in the selection ratio of the SiO_2 film layer relative to the SiN_x film layer by forming a carbon film (protective film) at the shoulder of the SiN_x film layer exposed inside the contact holes and makes it possible to form contact holes achieving a high aspect ratio by minimizing the accumulation of carbon at the contact hole bottoms.

A second object of the present invention is to provide a new and improved etching method that eliminates excessive etching which may cause damage to the shoulder of the SiN_x film and achieves an improvement in yield by preventing defective insulation at the gates and the occurrence of dialectic breakdown.

DISCLOSURE OF THE INVENTION

In order to achieve the objects described above, according to the present invention, an etching method for plasma-etching an SiO_2 film layer covering an SiN_x film layer formed at a workpiece placed inside an

air-tight processing chamber by raising to plasma a processing gas induced into the processing chamber, which includes a first step in which the SiO_2 film layer is etched by using a mixed gas containing at least C_4F_8 and CO as a processing gas and a second step in which the SiO_2 film layer is etched by using another mixed gas containing at least C_4F_8 and CH_2F_2 as a processing gas before or after the SiN_x film layer becomes exposed, e.g., immediately before or immediately after the SiN_x film layer becomes exposed, is provided.

In this etching method in which CH_2F_2 is used as a constituent of the processing gas, fluorine radicals can be generated from CH_2F_2 as well as from C_4F_8 to increase the quantity of fluorine radicals generated during the process. As a result, even when forming contact holes with a high aspect ratio, fluorine radicals can reach the bottoms of the contact holes with a high degree of reliability to make it possible to etch the bottoms while removing carbon accumulated at the bottoms of the contact holes, thereby facilitating the formation of contact holes with a specific depth.

In addition, since the bottoms of the contact holes can be etched with a high degree of reliability, it is not necessary to over-etch the workpiece and thus, damage to the SiN_x film layer exposed inside the contact holes and, in particular, damage to the shoulder of the SiN_x film layer can be prevented. As a result, since the insulating film layer covering the gates protected by SiN_x film layer or the gates themselves are not exposed inside the contact holes, defective insulation at the gates and the occurrence of dialectic breakdown are prevented to achieve an improvement the yield. Furthermore, since the bottoms of the contact holes can be etched while sustaining a specific etching rate, the length of time required to perform the etching process can be reduced to achieve an improvement in throughput, as well.

Since CH_2F_2 constituting the processing gas contains carbon

atoms, a carbon film to constitute a protective film can be formed at the inner wall surface of the contact holes with a high degree of reliability as in an etching method which utilizes a processing gas containing CO. Consequently, the inner wall surface of the contact holes are not etched readily, to prevent formation of contact holes with a bowed shape. Moreover, with the SiN_x film layer exposed inside the contact holes and, in particular, the shoulder of the SiN_x film layer, covered with the carbon film, the shoulder do not become etched and, therefore, damage to the shoulder is prevented. In addition, since fluorine radicals reach the bottoms of the contact holes with a high degree of reliability even though the processing is performed on the workpiece in a carbon-rich atmosphere in this manner, carbon does not accumulate at the bottoms of the contact holes.

Since the etching process is performed by using a mixed gas containing, at least, C_4F_8 and CO, the workpiece can be processed as fast as in the etching method in the prior art described earlier in a carbon-rich atmosphere. As a result, a carbon film is formed at the inner wall surface of the contact holes with ease and the etching process can be completed quickly without bowing the shape of the etched contact holes.

In addition, since the etching process is implemented by switching to another mixed gas containing at least C_4F_8 and CH_2F_2, before or after the SiN_x film layer becomes exposed, the workpiece can be processed in a carbon-rich and radical-rich atmosphere. Thus, the carbon accumulated at the bottoms of the contact holes can be removed to achieve reliable etching at the bottoms, and with the occurrence of an etching stop prevented, an improvement in the penetration is achieved. Furthermore, since the use of such a processing gas makes it possible to prevent accumulation of carbon at the bottoms of the contact holes while depositing a carbon film at the

shoulder of the SiN_x film layer, contact holes achieving a specific shape can be formed.

Moreover, by adding an inert gas into the mixed gas containing at least C_4F_8 and CH_2F_2 or adding an inert gas into the mixed gas containing at least C_4F_8 and CO, the various processing conditions such as the etching rate can be easily adjusted.